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A P300-based BCI System for Controlling Computer Cursor Movement

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***Abstract*—A P300-based BCI (brain-computer interface) system for controlling the movement of the cursor displayed on the computer screen was proposed and evaluated. On the LCD computer screen, the cursor was displayed with the surrounded eight small circles, each of which was blinked sequentially in a random order. Five healthy subjects were requested to gaze at one of the circles placed in the preferred direction. The P300 activities elicited by the random blink of the target circle were detected by pattern classifier and they were used to move the cursor to the same direction as the target circle. It was shown that all of the subjects could control the movement of the cursor to their preferred direction by moving their gaze point in a short distance. This system can be applied to the voluntary control of the movement of the computer cursor, and the navigation of robot or video camera, without using users' extremities.**

I. Introduction

The BCI (brain-computer interface) is the interface system which enables the users to control external devices without using their own extremities. The brain activation is measured non-invasively e.g. by EEG or NIRS, and the measured data is analyzed to extract user's own intention or "thoughts".

The BCI system that detects the P300, one of the event-related potentials measured by EEG, was proposed and was successfully applied to the virtual keyboard ("P300 speller") [1]. On the P300 speller system, characters are displayed on the computer screen, and one or some of them (e.g. row or column of the displayed character matrix) are blinked in a random order. Subjects are requested to gaze at the preferred character, and the system detects the P300 component elicited by the blink of the target character.

The P300-based BCI can also be applied in the auditory domain. The auditory BCI systems for the selection from two (right or left) or more source directions by the binaural auditory stimuli [2, 3], and from multiple auditory streams presented simultaneously to one ear [4] have been proposed.

In this article, a P300-based BCI system for controlling the movement of the computer cursor displayed on the computer screen was proposed and evaluated. The computer cursor was displayed on the LCD computer screen with surrounding eight small circles, each of which was blinked in a random order. Subjects were requested to gaze at one of the circles in the preferred direction to move the cursor. The P300 elicited by the blink of the target circle was detected and it was used to control the movement of the cursor.

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II. Methods

A. System

The schematic diagram of the present system is shown in Fig. 1. The experiments were executed by using two personal computers and a biosignal amplifier. The measured EEG data was acquired and processed on the first PC (PC1). On the second PC (PC2), computer cursor with surrounding circles was visually presented to subjects, and the the cursor was moved according to the detection of the elicited P300.

PC1 acquired the amplified EEG data and the trigger signal, which was generated by the photo-detector mounted on the 17-inch LCD display (1024 × 768 pixels) connected to PC2. Thus the exact timing of the blink of circles could be also acquired by PC1.

On PC1, pattern classifier was applied to the acquired EEG data to detect P300 online. If P300 was detected, the corresponding index of the blinked circle (control signal) was transferred to PC2 via digital I/O for controlling the movement of the cursor.

Both PCs worked on MATLAB on Windows XP Professional. In addition, Cogent 2000 Toolbox [5] was used to present the visual stimuli on PC2.

B. Experiments

The experiments in this study were approved by the Ethics Committee on Clinical Investigation, Graduate School of Engineering, Tohoku University, and were performed in accordance with the policy of the Declaration of Helsinki.

Five male volunteers took part in the experiment as subjects. The EEG was recorded with Ag-AgCl electrodes at five locations (FCz, Cz, C1, C2, CPz) and referred to right earlobe with a left earlobe ground. The signal was amplified (gain × 500) and band-pass filtered (0.15~100 Hz). The filtered signal and the trigger signal (described above) were acquired by PC1.

C. Stimuli and Paradigm

The visual stimuli were presented to subjects by using the

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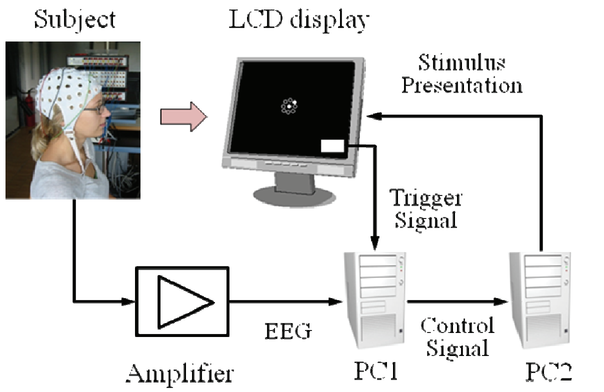

Fig. 1. Experimental system. Amplified EEG data was acquired and analyzed to detect P300 component by PC1. The onset of the blink of the circle was detected by photo-sensor placed on the surface of the LCD display for the use of the epoch extraction from raw EEG data using time window. PC2 controls the visual stimulus presentation (blink of the circles and the movement of the cursor). The control signal, result of detection of P300 was sent from PC1 to PC2 to realize the movement of the computer cursor.

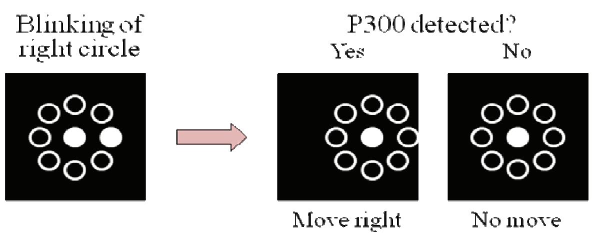

Fig. 2. Schematic diagram of the visual stimuli. Visual stimuli consisted of the computer cursor and the surrounding eight open circles. If the P300 elicited by the blink of one of the circles was detected, the cursor and surrounding circles were moved to the same direction of the blinked circle.

LCD computer monitor connected to PC2. The computer cursor (white filled circle) was surrounded by eight white open circles (Fig. 2). The distance between cursor and circles was 2 cm. During experiments, one of the circles was randomly selected and was blinked (changed to a white filled circle) with a fixed SOA (stimulus-onset asynchrony). The duty-cycle was set to 0.5.

During experiments, subjects were requested to gaze at one of the target circles to move the cursor into the same direction.

D. Data Analysis and Cursor Movement

EEG responses to the blink of the circles were extracted by using time window (−100~500 ms) relative to the onset of the blink, which was found by the trigger signal from the photo-detector. The extracted data was baseline corrected using the averaged potential at −100~0 ms. To remove the data with artifacts, the epoch data whose amplitude exceeded ±50 μV was discarded and excluded from further analyses.

On the online experiments, the Fisher's LDA (linear discriminative analysis) [6] was applied to all the raw epoch data during online experiments to detect P300 activities elicited by the blink of the target circle at which subjects gazed. The epoch data was low-pass filtered (60 Hz), and down sampled to 125 Hz. And the data at time 0~500 ms (63 points × 5ch = 315 dimensions) was used as a feature vector.

If the P300 activity was detected by pattern classifier, it was attributed to the cursor which was blinked at around 300 ms before the detection, and its index was transferred to PC2 as a control signal to realize the cursor movement.

On PC2, the position of the computer cursor with eight circles was updated according to the control signal, so as to move into the same direction as the identified circle by which the P300 was elicited. The step of the movement of the computer cursor was 10 pixels.

III. Results and Discussion

First of all, the relationships between P300 amplitude, latency and SOA of visual stimuli were evaluated. Next, the online experiments to control the movement of computer cursor were executed to evaluate the present BCI system.

A. Experiment 1: Relationship between SOA and P300

The relationship between SOA and the P300 activities elicited by the blink of the target circle was evaluated.

Subjects were requested to gaze at one of the circles at up, down, left and right positions. SOA was set to 200, 400, 600 and 800 ms. Totally 16 sessions of experiments were executed, and target circle to be gazed and SOA were not changed in a session. Total number of blinks in each session was 320 (40 blinks × 8 circles).

In this experiment, pattern classifier was not used, and the position of the computer cursor as well as the surrounding circles was not changed during the experiments.

The measured data was analyzed offline. The EEG responses to the blink of the target and non-target circles were separately averaged, and the peak amplitude of the P300 components was investigated.

The averaged P300 responses elicited by the blink of the target and non-target circles are shown in Fig. 3, and the peak amplitudes of the P300 responses (difference waveform of the responses to target and non-target circles) are depicted in Fig. 4. It was shown that the P300 components were elicited by the infrequent blink of the target circle for each SOA.

B. Experiment 2: Online Experiments

Next, the online experiments were executed and the accuracy of the detection was evaluated. SOA was set to 600 and 800 ms and the difference of the two conditions was investigated.

Before starting the online experiments, the responses to the infrequent blinks of the up, down, left and right circles were measured to obtain the sample data for designing LDA pattern classifier, which was used to determine whether P300 was generated or not. In this experiment, no pattern classifier was applied and the cursor was not moved. The number of the

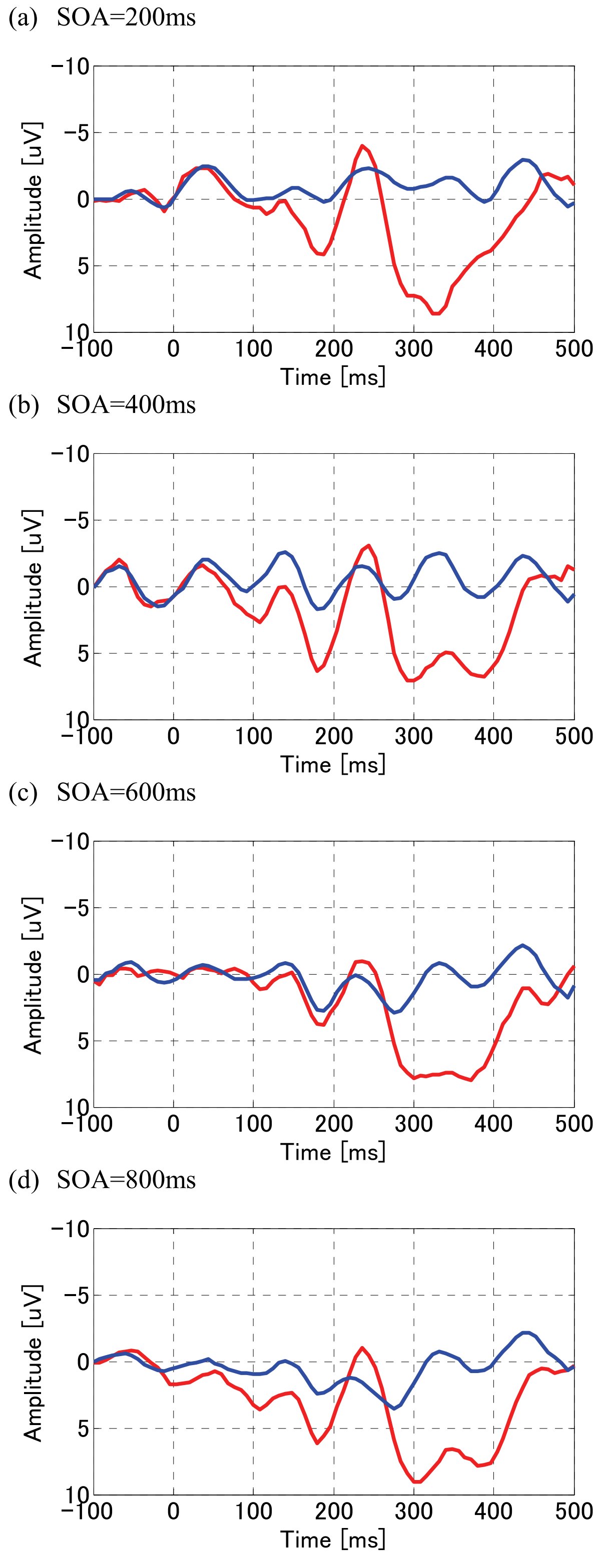

Fig. 3. Averaged responses to the blinks of target (red) and non-target (blue) circles (Experiment 1, Subject D, electrode location Cz)

blinks of the target circle (i.e. the number of the test data) was 60 each (totally 240). All the 240 responses were used offline to design the LDA classifier.

The online experiments were executed for another two days. On each day, subjects were requested to gaze at up, down, left and right circles in the separate sessions for each SOA. The total number of sessions on each day was 8. The number of trials in each session was 40.

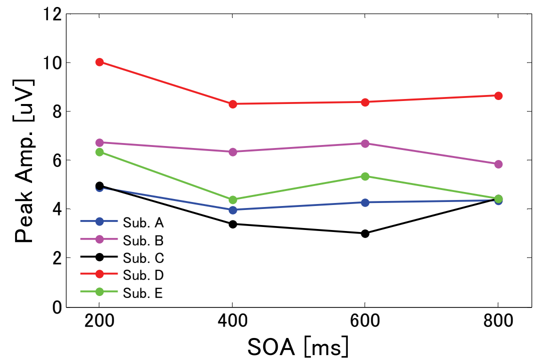

Fig. 4. Relationship between peak amplitudes of the elicited P300 and SOA (Experiment 1). The amplitudes of difference (subtracted) response to the blinks of target and non-target circles are shown.

By the online experiments, it was shown that all five subjects could control the cursor movement by gazing at the target circle. The example of the locus of the cursor movement controlled by the present BCI system is shown in Fig. 5.

To evaluate the accuracy of pattern classification, the true-positive rate (TPR [%]), false-positive rate (FPR [%]) and information bit rate (IBR [bit/min]) were investigated. The TPR, FPR and IBR on each subject are shown in Fig. 6. And the TPR, FPR and IBR averaged over subjects are shown in Fig. 7. The TPR and FPR were defined as the rates to detect P300 when the target and non-target circles were blinked, respectively. The IBR was defined by the following formulas:

$$IBR = MB \tag{1}$$

$$B = \log_2 N + TPR \log_2 TPR + (1 - TPR)\log_2[(1 - TPR)/(N - 1)] \tag{2}$$

where N is a number of possible choices (=8), and M is the number of blinks of the target circle.

From Fig. 6, it was shown that four subjects (except Subject A) achieved the TPR of 53~72% and FPR of 22~30%, and IBR was 9~13 bit/min on these four subjects. In Fig. 7, the TPR and FPR on 800 ms SOA were larger than those on 600 ms SOA ($p < 0.005$), whereas the IBRs on two SOA conditions had no significant difference.

The present BCI enables the users to control cursor movement by gazing at the blinking circle in the preferred direction without doing any additional tasks (e.g. motor imagery). Such system can also be used for navigating the robots or controlling the view of video cameras.

IV. Conclusion

The BCI system to control the movement of computer cursor by detecting P300 elicited by the blink of gazed circle

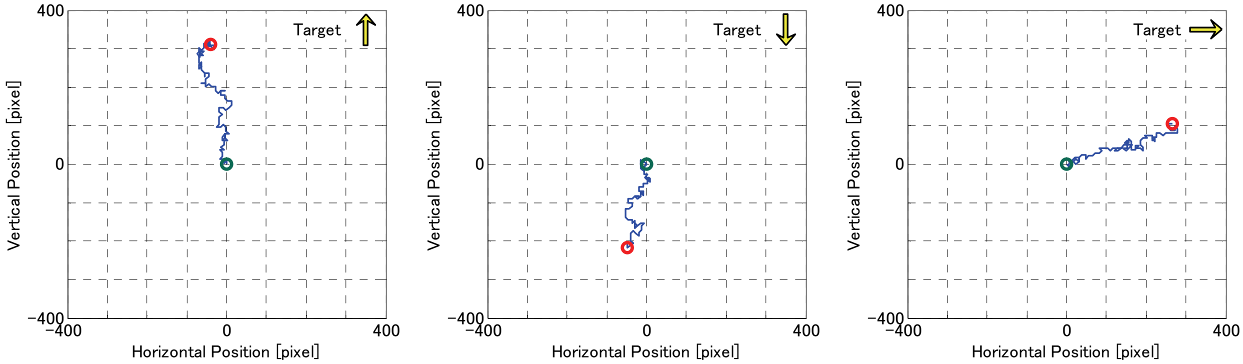

Fig. 5. Example of the locus of the cursor movement during online experiments (Experiment 2, Subject C).
The initial and the final position of the cursor are depicted by green and red open circles, respectively.

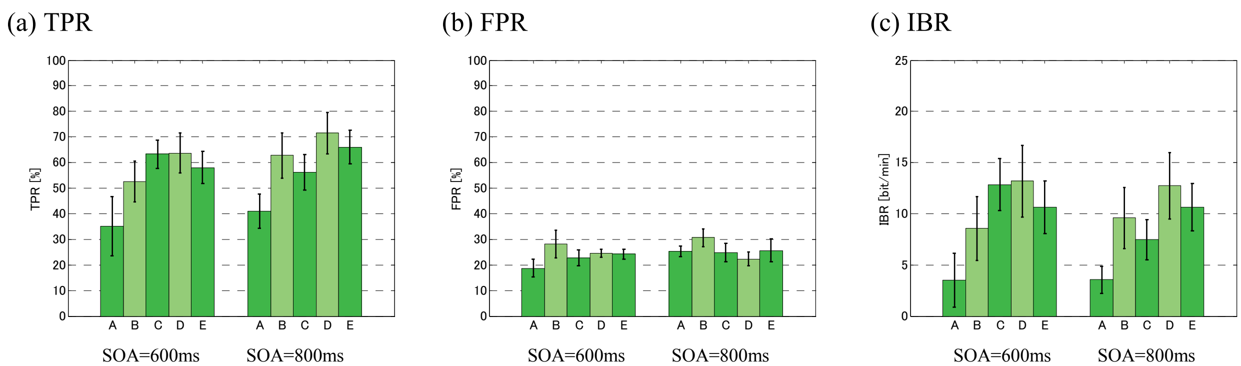

Fig. 6. TPR, FPR and IBR on each subject (Experiment 2)

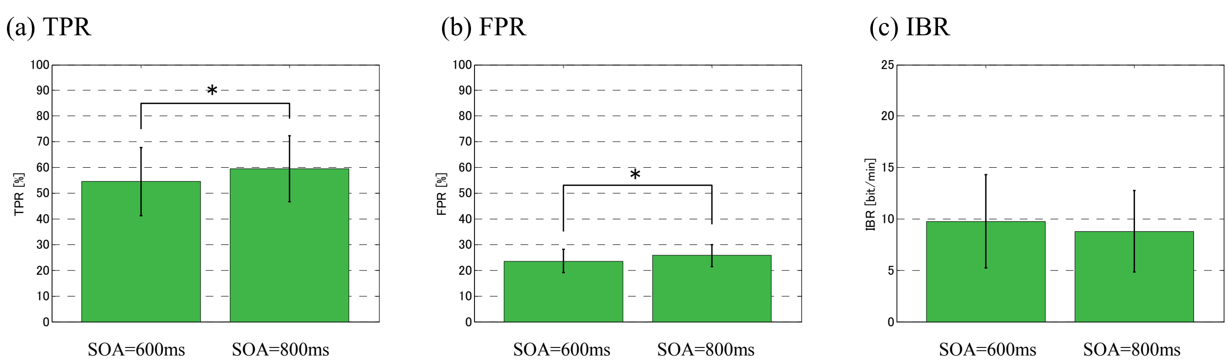

Fig. 7. TPR, FPR and IBR averaged over subjects (Experiment 2) *: $p < 0.005$

was proposed and evaluated. It was shown that this system could control the cursor movement into the desired direction on all five subjects. Such a system can be applied to control computer cursor and the navigation of robots or video camera without using users' extremities. The investigation of the EEG data analysis to improve the accuracy of the pattern classification was left for the further study.

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